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TECHNICAL REPORT

68-34-CM

DEVELOPMENT OF A MULTIDIRECTIONAL-STRETCH SPACER FABRIC

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M. W. Olson, A. S. Glowacki

and R. A. Fowkes

Uniroyal, Inc. Wayne, New Jersey

Contract No. DA19-129-AMC-1069 (N)

December 1967

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

US ARMY MATERIEL COMMAND

Clothing and Organic Materials Laboratory

C&OM-39

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FOREWORD

This is the final report on the work performed by Uniroyal, Inc. under Contract No. DA19-129-AMC-1069(N). The duration of the contract, as amended, was from June 30, 1966 to December 29, 1967.

The contract was under the supervision of the Clothing and Organic Materials Laboratory, U.S. Army Natick Laboratories, with Mr. V. D. Iacono serving as Project Officer. The Project Administrator was D. Shichman of the Engineering Research Section, Research Center of Uniroyal, Inc., Wayne, New Jersey.

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Director
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CONTENTS

LIST OF FIGURES

ABSTRACT

An investigation was conducted to develop a 3-dimensional spacer fabric for use in the air distribution system of the experimental thermalibrium protective clothing system designed by the U.S. Army Natick Laboratories. A multidirectional-stretch spacer fabric known as "monocoil" made by interlocking coiled monofilaments in a square woven fabric-like configuration, was selected as the candidate system.

A variety of materials were studied. Based on analysis of available monofilaments, polyester was chosen as the material to be used in the construction of this 3-dimensional fabric.

Numerous monocoil designs were fabricated and tested for air flow, compression, weight, and stretch characteristics. A construction which met specifications was selected for quantity production. Two-hundred linear yards of experimental spacer fabric 42-48 inches wide were manufactured.

During development, it was found necessary to apply a protective or restraining cover to control stretch and enable handling of the spacer fabric. Cover materials included high-stretch power net, Jersey-knit Nomex fabric, and neoprene sheeting.

DEVELOPMENT OF A
MULTIDIRECTIONAL-STRETCH SPACER FABRIC

I. MATERIALS SELECTION

The first step in developing the 3-dimensional spacer fabric consisted of testing presently available monofilament materials. These materials are listed and classified for specific gravity, heat resistance, and size availability in Table I. In selecting this list of materials, the factors of strength, weight, flame resistance, and heat setting properties were considered. Two materials which rate high in heat resistance, Nomex and polybenzimidazole, are not presently available in monofilament form.

TABLE I

CANDIDATE MONOFILAMENT MATERIALS FOR EVALUATION

Candidate Monofilament Material	Specific Gravity gm/cc	Heat Resistance @66 psi fiber stress °F	Monofilament Diameters Available (mils)
Polypropylene	0.902	220	8 - 15
Polyethylene	0.95	160	9 - 16
Nylon 6, 6	1.14	360	4 - 20
Polyester	1.37	Melts @ 420	6 - 20
Saran-Copolymer	1.61	180	8 - 24
FEP-Teflon	2.14	Melts @ 540	

Polypropylene and polyethylene were not considered suitable because of their low heat resistance characteristics.

To determine the spring characteristics of the remaining materials, several 12-inch coils were suspended from one end for three days at ambient conditions. Both Teflon and Saran coils gradually extended 200 percent in length during this period and would not return to their previous state when laid flat. The polyester and nylon coils did not stretch any measurable amount, and tests with them were continued. Both nylon and polyester have good heat set properties, but nylon was finally ruled out because of its lower melting point.

A final test was made on single coils of polyester in .008 inch, .010-inch, and .016-inch diameter, fabricated and heat-set on a 1/8-inch diameter mandrel. The purpose of this test was to observe the creep

behavior of the formed coils at various levels of extension. The samples were extended and kept in the stretched condition for 24 hours. At the end of that period all samples were allowed to relax 5 minutes. The final measurement indicates the permanent set or creep at the various extensions. At the 30-50 percent level no change was observed. Table II tabulates test results.

TABLE II

CREEP MEASUREMENTS OF POLYESTER COILS

Monofilament Diameter (inches)	Spring Length at Start (inches)	Extension[a] (%)	Relaxed[b] Length (inches)	Length Increase (%)
.008	2	30	2.0	---
	2	100	2.42	21
	2	200	2.85	42.5
	2	300	3.3	65
	2	400	3.85	92.5
	2	500	4.25	112.5
.010	2	30	2.0	---
	2	100	2.31	15.5
	2	200	2.7	35
	2	300	3.05	52.5
	2	400	3.65	82.5
	2	500	4.2	110
.016	2	30	2.0	---
	2	100	2.34	17
	2	200	2.72	36
	2	300	3.3	60
	2	400	4.05	102.5
	2	500	4.9	145

(a). 24 hours at indicated level.
(b). Sample relaxed 5 minutes.

As a result of this evaluation, all materials supplied under this contract have been made of polyester monofilament.

II. SPACER FABRIC CONSTRUCTION

The main variables in spacer fabric construction are:

1. Filament diameter
2. Diameter of winding mandrel
3. Coil spacing per inch of fabric
4. Coil pitch in finished fabric

The formula for determining the critical buckling pressure of a uniform circular ring having a uniform radial pressure is

$$p^1 = \frac{3EI}{R^3} \qquad (1)$$

where p^1 = critical buckling pressure, psi
I = moment of inertia = $.049\ (D^4 - d^4)$
E = Young's modulus (constant for a given material)
R = mean radius
D = outside diameter of ring
d = inside diameter of ring

Eliminating the constants we have

$$\propto \frac{D^4 - d^4}{R^3} \qquad (2)$$

Thus, it can be seen that by holding the mean radius constant, an increase in filament diameter will result in a stronger coil. It also produces greater weight and a smaller opening which decreases air flow with a fixed pressure head.

Referring again to Equation 2, an increase in mean radius with a fixed filament diameter will reduce the coil strength rapidly, resulting in increased weight but producing a larger opening and increased air flow for a fixed pressure head.

Our first series of samples (Table III) was made on 1/16-inch, 1/8-inch, and 3/16-inch diameter mandrels. The polyester filaments were tightly wrapped on the steel mandrels and heat set in a hot air oven according to the following schedule:

.008" diameter polyester - 60 seconds at 300°F
.010" diameter polyester - 120 seconds at 300°F
.016" diameter polyester - 180 seconds at 300°F

TABLE III

EXPERIMENTAL MONOCOIL FABRIC CONSTRUCTIONS

Sample No.	Mandrel Diameter (inches)	Filament Diameter (inches)	Relaxed Coil Spacing (inches)	Relaxed Pitch (turns/inch)	Weight (Ounces/Yard^2)
1	1/8	.010	3/8	42	5.0
2	3/16	.010	3/8	42	9-1/2
3	1/16	.010	3/8	42	14
4	1/8	.016	3/8	42	21
5	1/8	.008	3/8	42	4
6	1/8	.010	1/2	42	5
7	1/8	.010	1/4	42	13
8	1/8	.010	3/8	63	14
9	1/8	.010	3/8	21	13
10	3/16	.008	3/8	42	--
11	1/16	.010	1/2	42	13
12	3/16	.010	3/8	21	9
13	1/8	.016	1/4	42	24
14	1/8	.008	3/8	63	4.0
15	1/8	.010	1/2	21	15.0
16	1/8	.010	1/4	21	10

After heat setting, the coils were removed from the rods and stretched over the pins of an assembly frame at the desired spacing. To help hold the coils in place, a small amount of cement was placed on each intersection while on the assembly frame. Three samples of each configuration were fabricated to obtain an average value of compression, stretch, weight, and air flow.

Figure 1 shows a typical sample in the stretched condition on the assembly frame, and Figure 2 shows the same fabric after removal from the frame.

A representative sample of each experimental construction was tested for compression per Military Specification MIL-C-43204(GL). The sample size was approximately 4 square inches, whereas the Military Specification called for a sample size of 36 square inches.

The samples were also tested on an Instron Tester by using a compression cell. The initial thickness, compressed thickness, and thickness

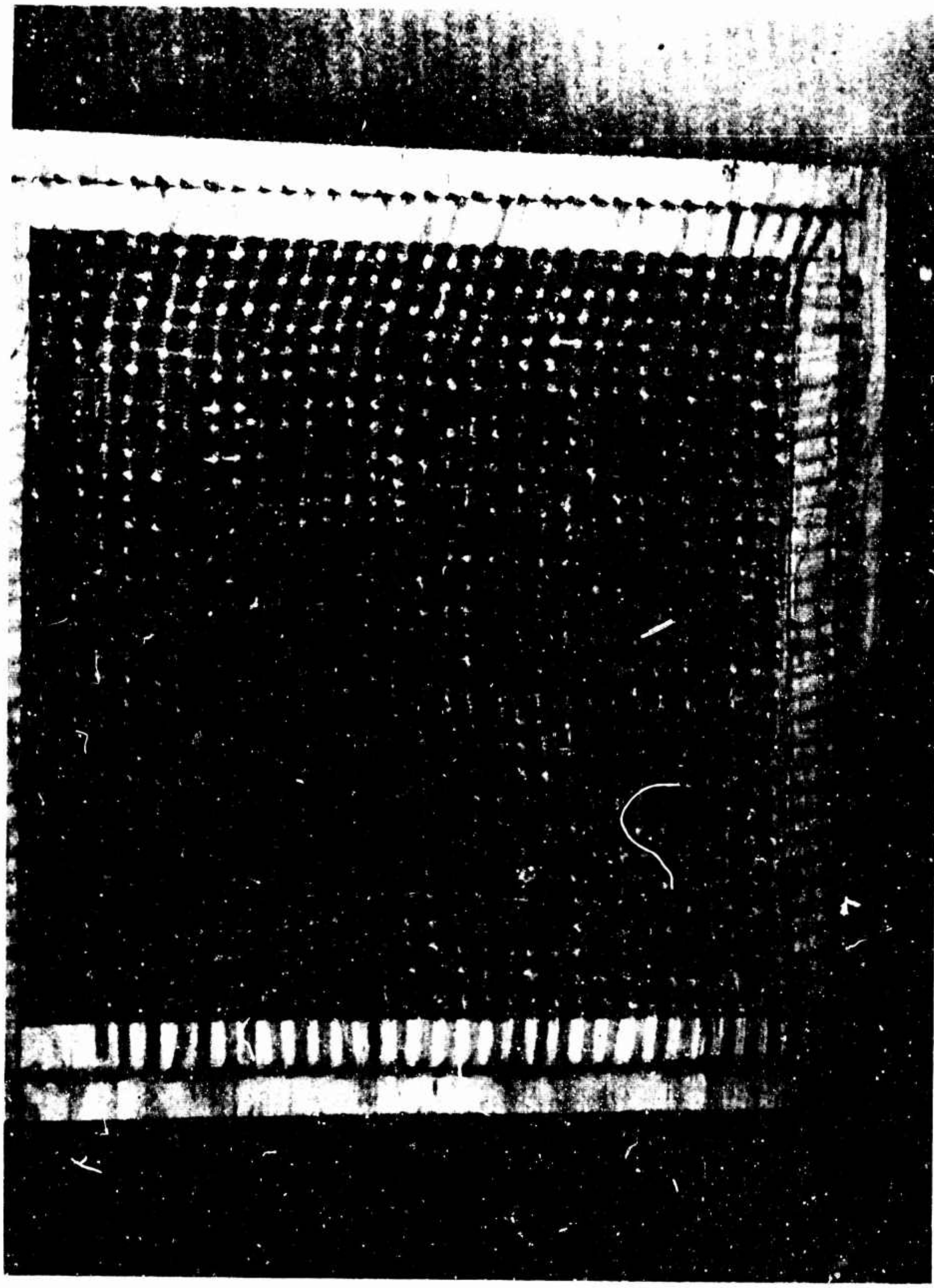

Figure 1. Spacer Fabric on Assembly Fixture

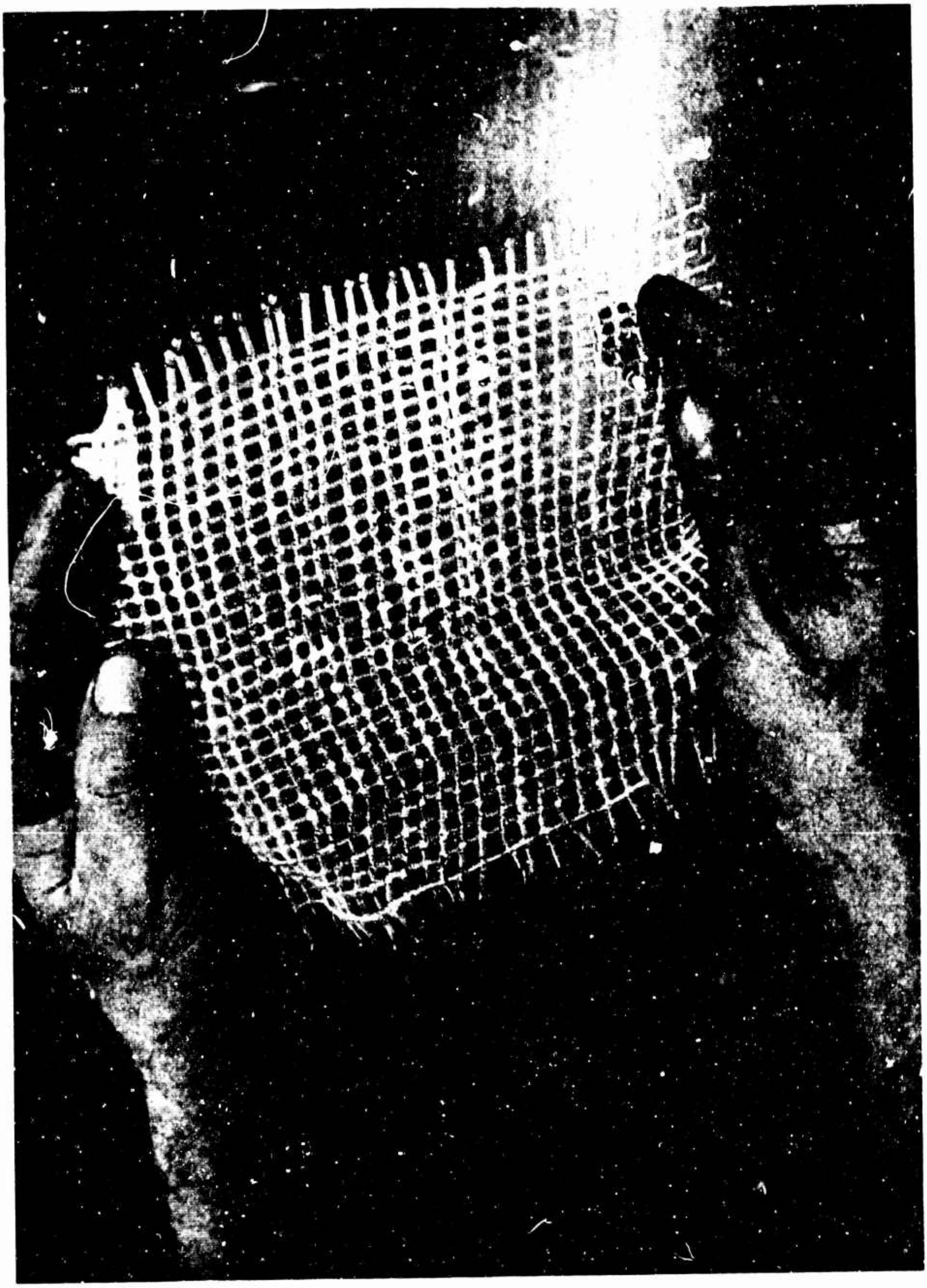

Figure 2. Relaxed Spacer Fabric Sample

after release of compressing force were determined (Table IV). In each case the material recovered 90 percent of its initial thickness when tested to a unit loading of 10 pounds per square inch.

TABLE IV

COMPRESSION TESTS OF MONOCOIL FABRICS

Sample	Initial Thickness Inches, .01#/in^2	Compressed Thickness Inches, 10#/in^2	Thickness after Compression Inches, .01#/in^2	Recovery %
1	0.176	0.120	0.166	94.5
2	0.240	0.042*	0.230	96.0
3	0.092	0.084	.089	96.6
4	0.186	0.156	0.182	98.5
5	0.165	0.026*	0.150	91.0
6	0.161	0.033*	0.150	93.3
7	0.160	0.136	0.155	96.7
8	0.087	0.080	0.085	96.5
9	0.149	0.142	0.148	99.5
10	No test	---	---	---
11	0.090	0.081	0.087	96.5
12	0.222	0.107	0.213	96.5
13	0.181	0.157	0.177	97.0
14	0.157	0.030*	0.145	92.5
15	0.152	0.145	0.152	100.0
16	0.158	0.147	0.157	99.5

* Coils collapsed.

These first samples showed good compressive strength and fair flexibility. However, flow rates (when air was passed through edgeways) were generally poor compared to the control (spacer fabric presently used in the experimental thermalibrium clothing).

The reason for the low flow rate becomes clear on visualizing a cross section of the fabric. We see, as in the following diagram, longitudinal coils and transverse coils.

The longitudinal coils serve as tubes to conduct air flow. The transverse coils, on the other hand, impede air flow. The amount of flow is therefore dependent on coil spacing. When the longitudinal coils are widely spaced (as in our first samples), air flow is low, but air flow can be maximized by placing the coils close together. However, the stretch characteristics of the fabric are reduced when the coils are close together, so the final choice of coil spacing is a compromise between these two factors.

The stretch in the fabric using a given monofilament will vary according to the formula for spring deflection,

$$F = \frac{8PND^3}{Gd^4} \qquad (3)$$

where F = deflection
P = load applied
N = number of active turns
D = mean diameter of spring
G = torsional modulus of elasticity (a constant for a given material)
d = filament diameter

According to Equation (3), a stiffer material would be obtained by increasing filament diameter, reducing the coil diameter, and reducing the number of active turns. Also, increasing the end count of the material, i.e., the number of coils per inch, will increase the stiffness.

In a second series of experiments the number of variables was kept to a minimum. Every sample was made with minimum spacing between coils. In material made of .016-inch-diameter filament the coil spacing was such that there were only one or two turns of the coil between intersections. With filaments of .010-inch diameter or smaller, there were 3 to 5 turns between coil intersections. These constructions are listed in Table V. Figure 3 shows some of these samples.

TABLE V

MONOCOIL FABRIC CONSTRUCTIONS

Sample Number	Fil.Dia. (In. x 10^{-3})	Extension[a] (%)	Mandrel Size (In.)	Coil Centers (In.)	Fabric Weight (Oz./$Yd.^2$)
P1	10	685	1/8	.187	13.4
P2	16	685	3/32	.187	25.1
P3	8	685	3/32	.125	13.0
P4	10	685	1/8	.187	12.1
P5	16	480	3/16	.187	20.4
P6	16	480	1/8	.187	24.4
P7	16	480	5/16	.375	16.6
P8	16	345	1/4	.375	14.6
P9	8	480	3/16	.250	9.6
P10	16	480	1/8	.375	20.8
P11	10	730	1/8	.375	12.5
P14	10	480	1/4	.312	10.3
P15	12	685	1/4	.312	12.1
Trilok Control	--	---	---	---	8.5

a. Extension of individual coils used to assemble the sample on the assembly frame.

To test the flow characteristics of this group of samples, a fixture was made that would hold a sample 1 inch wide x 12 inches long. Non-cellular foam is positioned against its face to compensate for variations in thickness along its length. Air was introduced at one end and traveled lengthwise through the sample. A flow meter was placed in the line. Also, a pressure tap at the inlet end was connected to a manometer to indicate the pressure forcing the air through. Figure 4 shows the experimental setup.

Figure 5 shows flow rate as a function of pressure drop for the group of samples listed in Table V with the control used as a reference material.

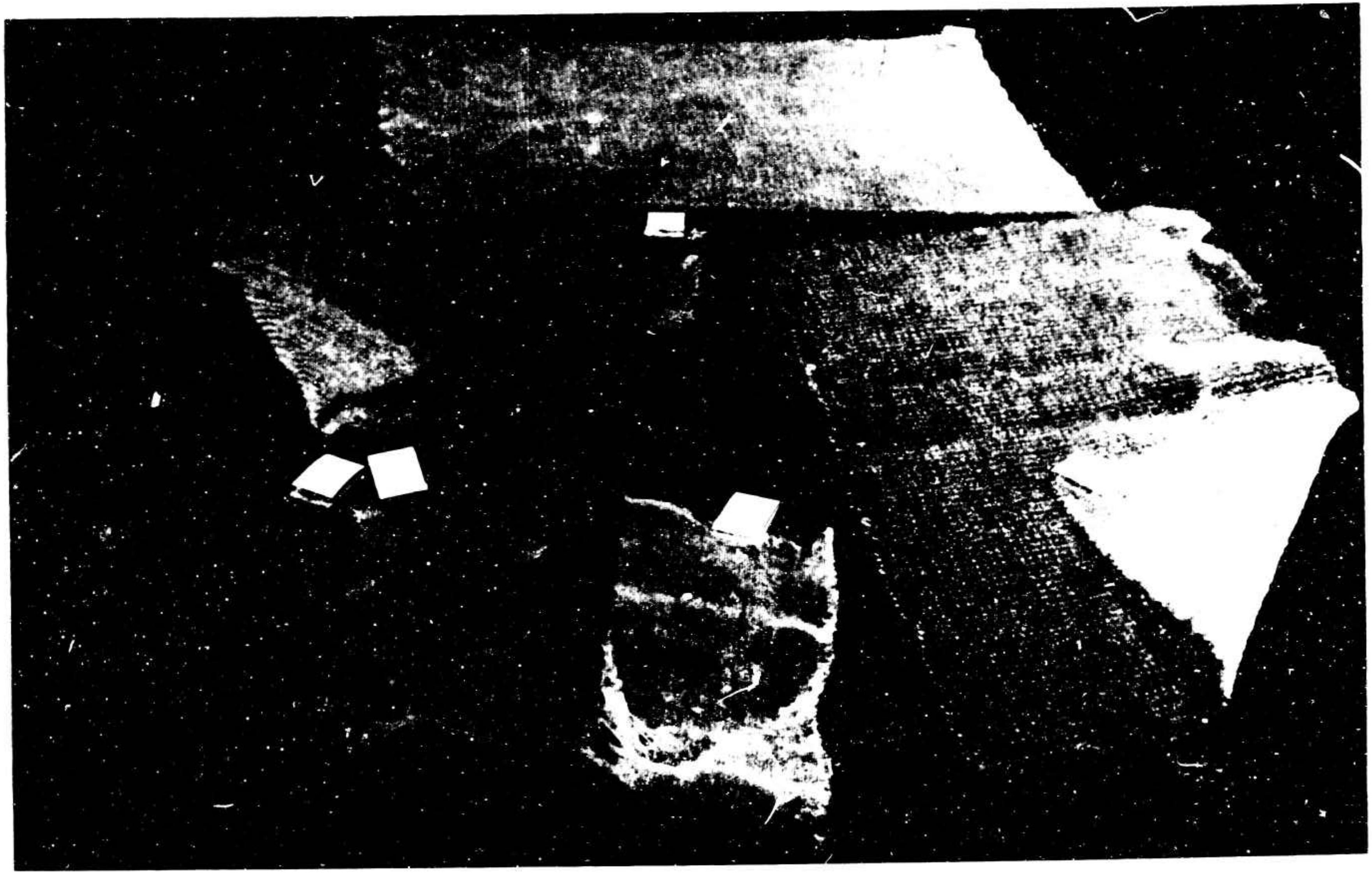

Figure 3. Various Constructions of 3-Dimensional Spacer Fabric

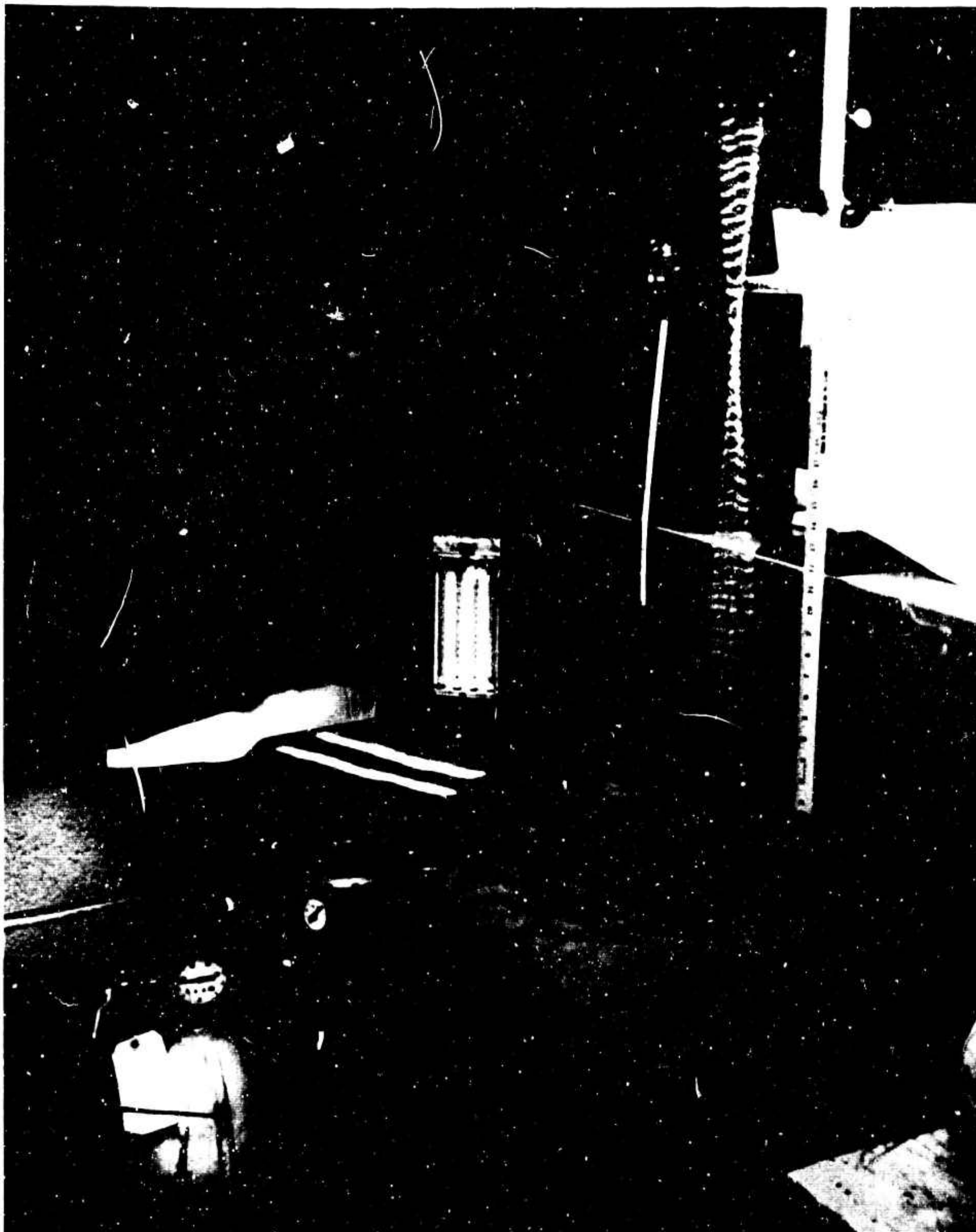

Figure 4. Flow and Stretch Tests

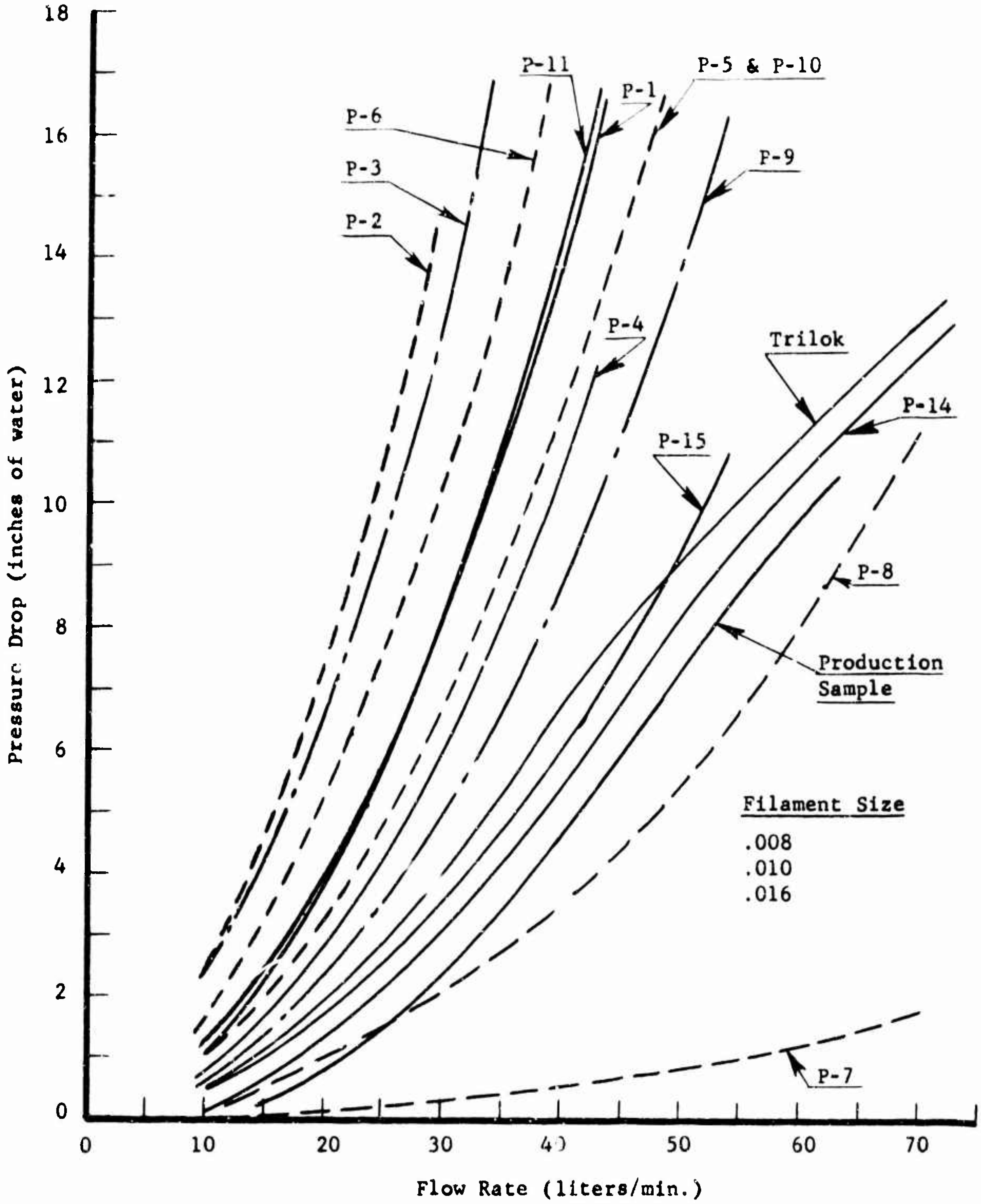

Figure 5. Air Flow Rate vs. Pressure Drop for Monocoil Spacer Fabric
Sample size: 1" wide x 12" long

Compression tests, as shown in Table VI, were made on selected samples with sample P-15 being tested as per Mil Spec MIL-C-43204(GL) with the exception that 8 psi loading was used instead of 10. The other samples were tested to determine the maximum load each could carry before collapse. The latter test was made in an Instron testing machine with the compression load applied through a 5-inch-diameter plate. A low loading was first maintained for 1 minute, and if the thickness of the sample stabilized after 15 or 20 seconds and there was no change for the remainder of the test period, the load was increased and maintained for another minute. This procedure was continued until the sample collapsed. The data from this test are shown in Table IV. Sample P-7 was not tested for compression strength, since it tended to spring into a ball instead of lying flat. This condition was due to its loose construction with high stretch in the coils.

Figures 6 and 7 show the load-carrying ability of sample P-15. The weight shown is a 6-inch-diameter steel bar 14 inches high.

To rate these samples, the following criteria were used:

1. Thickness - approximately 1/4"
2. Weight - 12 ounces per square yard or less
3. Flow rate - equivalent or superior to the control (currently used in experimental thermalibrium clothing at NLABS)
4. Compression - 8 pounds per square inch minimum load

Samples P-15, P-14, P-8, and P-7 were the only constructions having the desired flow characteristics. P-8 exceeded the weight limitation, although its stretch and compressive qualities meet specifications. P-7 had a high weight and was not a satisfactory construction as pointed out above. P-14 met the weight requirement and passed all tests except compression. P-15 was at the upper weight limit but passed all requirements.

A modification of P-15 was made by changing the number of coils per inch and increasing the stretch of each coil. This again was aimed at reducing the number of turns between coil intersections in the fabric. When this material was tested, it passed all requirements. The flow curve is plotted in Figure 5 and labeled Production Sample. Its weight was 11.2 ounces per square yard. It passed the compression load test of 8 pounds per square inch and met the stretch specifications. The sample is pictured in Figure 4 in the stretched condition. A 10-inch length stretched to 31 inches for 310 percent elongation.

TABLE VI

COMPRESSION TESTS - MONOCOIL SAMPLES

Sample Number	Initial Thickness (inches)	Thickness While Loaded (inches)	Thickness After Removal of Load (inches)	Load on 5" Dia. for 1 Minute (lbs.)	Load (psi)	% Recovery After 5 minutes
P3	.135	.103		200	10	
		.100		250	12.5	
		.100		300	15	
		.98		350	17.5	
		.98		400	20	
P5	.205	.172		200	10	
		.170		250	12.5	
		.168		300	15	
		.167		350	17.5	
		.165		400	20	
		.163		500	25	
		.160		600	30	
		.157		700	35	
		.148	.196	1000	50	96
			Maximum Instron Setting			
P8	.276	.230		200		
		.223		250		
		.214		300		
		.203		325 - would not hold		
P14	.225	.200		140	7	
				160 - collapse		
P15	.245	.212	.237	160	8	
	.237	.212	.235	160	8	
	.235	.212	.236	160	8	96.5
		.208		200	10	
		.205		220	11	
		.200		250	12	
				275 - would not hold		
Production Sample	.268	.227		160	8	

Figure 6. Spacer Fabric Supporting Steel Weights

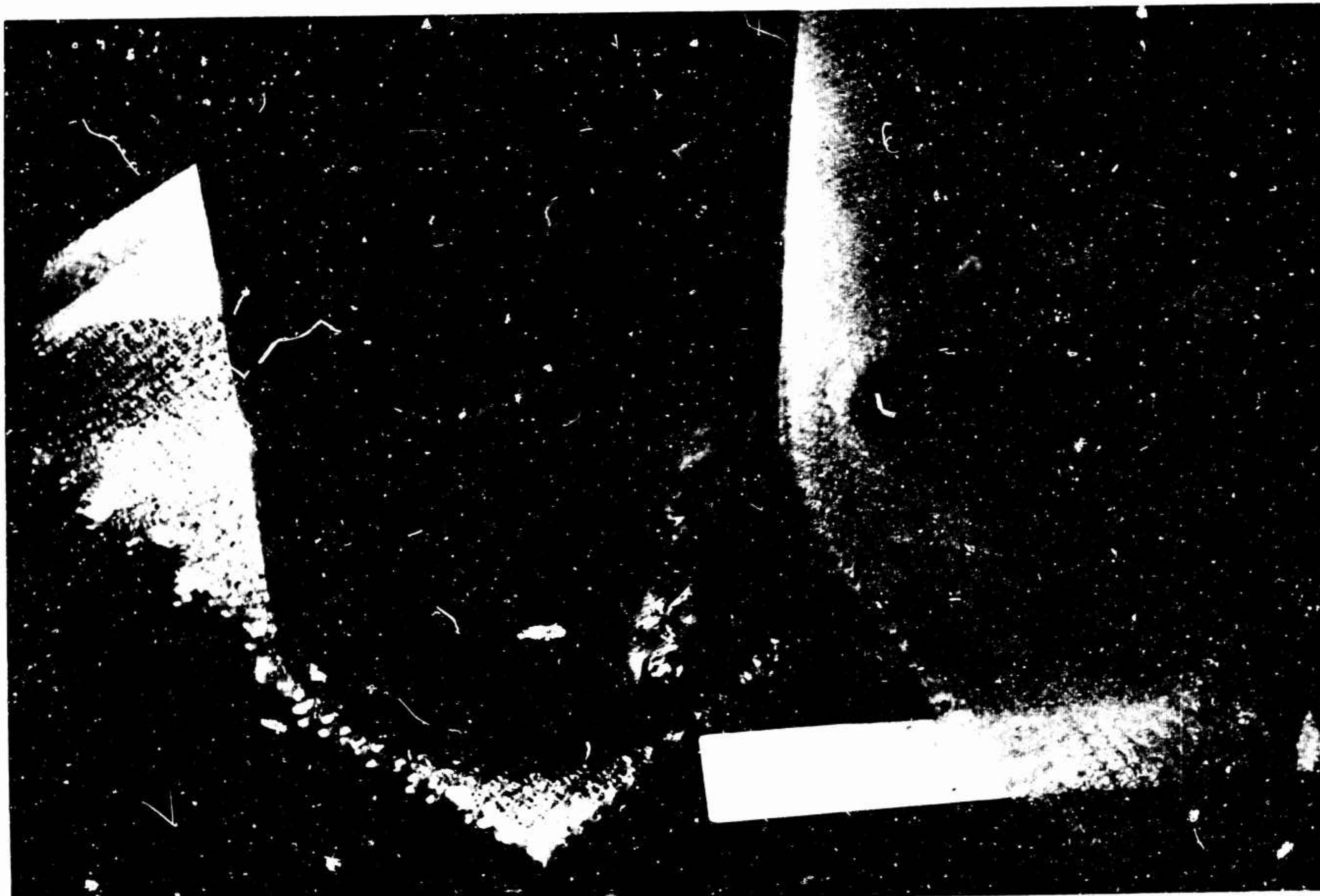

Figure 7. Close-up - Loaded Spacer Fabric

The 200 yards of material delivered under the contract were of this construction. Complete specifications are given in a later section of this report.

III. COVER MATERIAL

The high stretch characteristics of the spacer fabric caused excessive sagging when it was hung in a vertical plane and left unsupported for distances in excess of 4-6 inches. Also, the coils tended to tangle when pressed together, presenting a handling problem. Because of these considerations, it was necessary to ply or tack the spacer fabric to a supplementary stretch fabric or sheet.

Three cover materials were selected for evaluation - a high-stretch power net, a Nomex jersey-knit fabric, and Neoprene sheeting.

The following three methods of attaching the spacer material to the cover material were investigated:

1. Sewing in continuous seams
2. Tack sewing
3. Tack cementing

Figure 8 shows a sample of spacer fabric with a power net material sewn to both sides. Even with a light thread tension, the power net was pulled down into the spacer fabric, greatly reducing air flow through the spacer fabric.

Other samples were made by spot-tacking on 4-6 inch centers with a sewing machine. They were considered better than those made with continuous stitching, although at the tack points the cover material still pulled through the spacer fabric.

A well-known specialty sewing machine manufacturer was contacted to discuss the equipment required. After showing samples of the operation, sample stitches were made on a machine which could be set to tack by stitching approximately 4-10 stitches and then tying-off the ends. This type of equipment could be used but would require a multiple head setup with built-in traversing to handle material 42-48 inches wide and in long lengths. This type of operation was not economically feasible for this contract, due to the excessive costs required to design and build the stitching equipment.

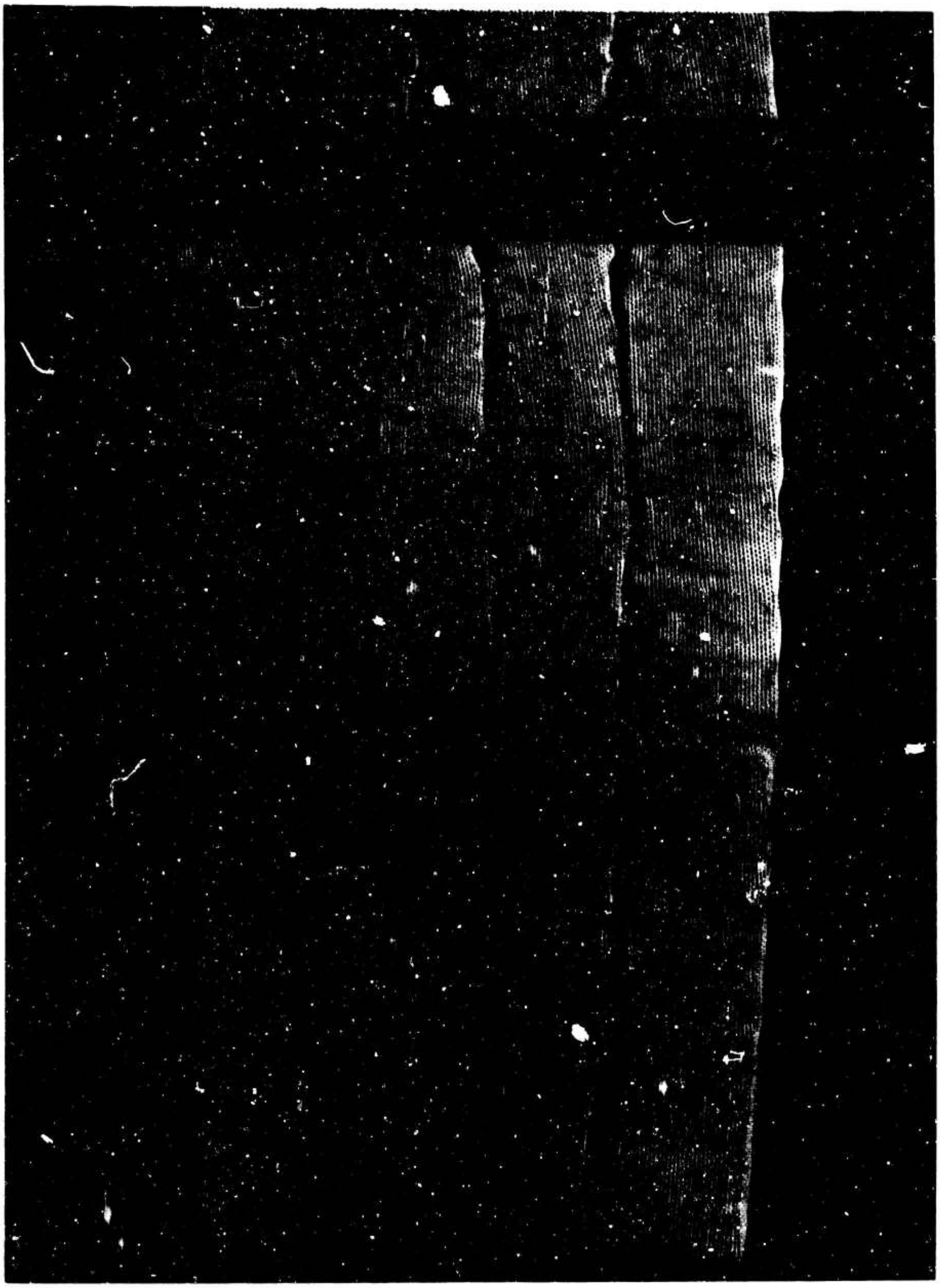

Figure 8. Cover Material Sewn to Spacer Fabric

Trial samples were fabricated using various cements and this method appeared to hold the most promise. The main drawback was the lack of flexibility in the cemented spot and also the tendency of the cement to flow out into the fabric. Best results were obtained with a high-viscosity, rapid-drying contact cement. This cement adhered well to the spacer fabric and to the various types of cover material being used.

The cover fabric was also attached to the spacer material by spraying the entire coil structure. This method was not acceptable, since it destroyed the stretch characteristics by cementing all the coils together.

As a result of this investigation, the cover fabric was attached by spot-cementing on 4-6 inch centers. Figure 9 shows a section of spacer fabric having the Nomex cover attached in this manner.

IV. ELECTRIC HEATING AND STATIC BUILDUP

Three spacer fabric test panels (approximately 15 inches wide x 20 inches long) with integral heating wire were fabricated in the following manner. Standard resistance wire having a nominal resistance of 1.6 ohms per foot was wrapped around a steel rod to produce coils with an outside diameter approximately equal to the thickness of the spacer fabric. Five heating coils were used, each heating coil containing approximately 32 feet of resistance wire and having a coiled length of about 80 inches. The coils were wired in a parallel circuitry providing 15.2 watts at 12 volts or 60.8 watts at 24 volts (AC or DC). This provides a watt density of about 24 watts/foot^2 at 24 volts. The coils were placed in the spacer fabric so that there was about 1 inch between adjacent rows (Figure 10). The lead wires consisted of multifilament copper wire and were mechanically crimped to the heater ends.

Several attempts were made to incorporate a ground wire into the spacer fabric. In each case a low-resistance ground wire could not be formed into coils that would maintain springlike properties. Higher modulus alloys that would provide the necessary spring properties were too stiff to be considered as potential grounding systems.

Two other methods of providing a grounding system were investigated. Both methods were based on incorporating grounding means into the cover fabric instead of into the spacer fabric itself. The first method involved knitting a .003-inch-diameter stainless steel yarn into the cover fabric. A sample was produced but the knitted steel yarn tended to gather the fabric instead of permitting it to lie flat. In addition, this method did not seem practical from the cost or

Figure 9. Spacer Fabric with Spot-cemented Cover Material

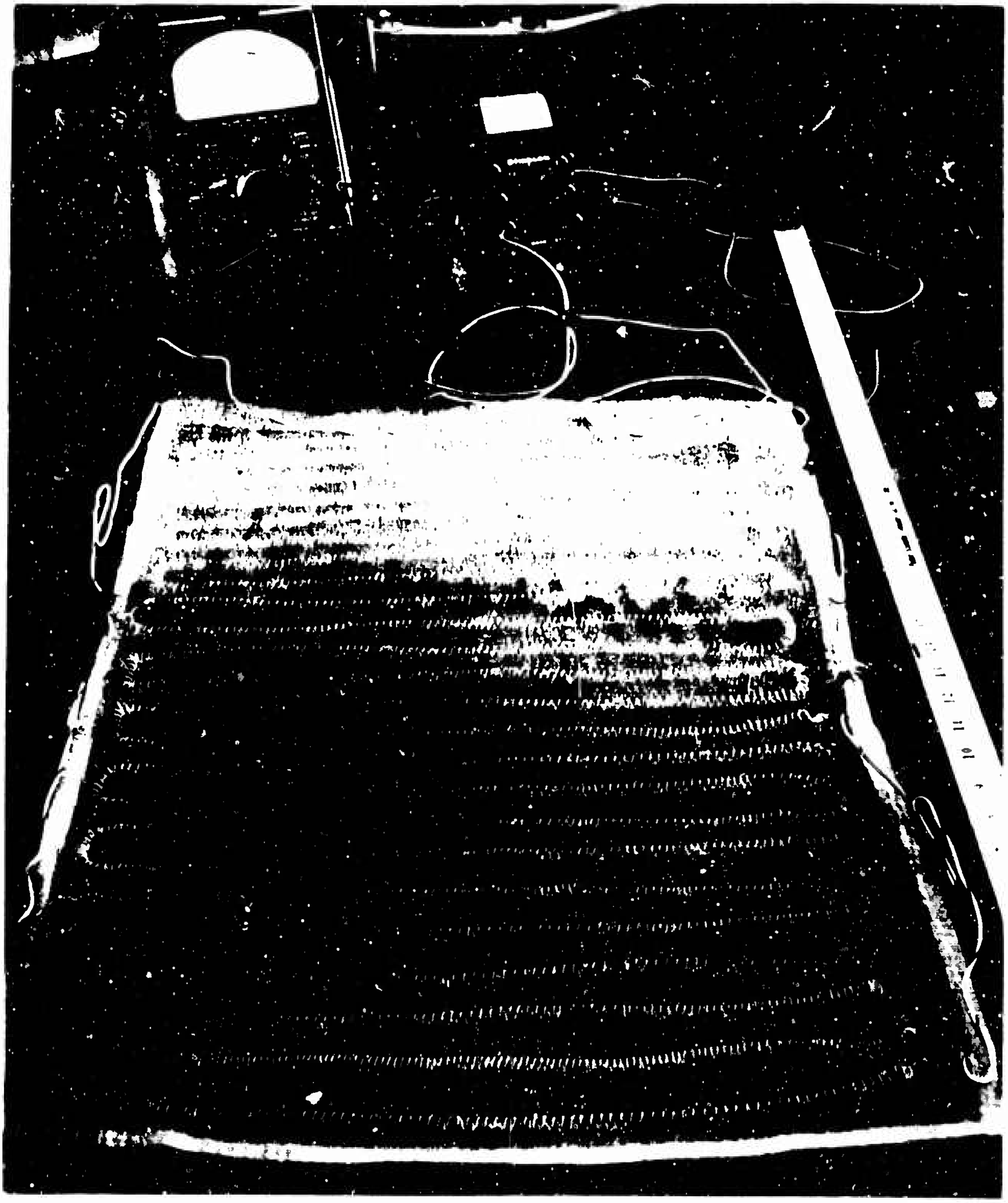

Figure 10. Spacer Fabric with Integral Heating Wires

manufacturing point of view. The second method consisted of weaving a fabric from a mixture of stainless steel and Dynel staple filaments. Because of the small filament size, no discomfort would be experienced by the wearer. A sample of this material was of low stretch but showed the method is feasible.

V. FLOCKING AND SPECIAL CONSTRUCTIONS

Flocking of the spacer material with a moisture-absorbent material was investigated by dusting cotton flocking over a spacer material that had previously been sprayed with cement. One coat of flocking adhered to the spacer fabric in a fairly uniform manner without affecting the stretch characteristics noticeably. As the flocking was built up, however, the sample became stiffer until its flexibility was entirely lost. The flocking used was of a powdery consistency, and better results could possibly have been achieved using a flocking with a more fibrous makeup and drawing it into the material with a vacuum or beater bar.

During the research stage, a small sample of spacer fabric was made using light steel wire of approximately .006-inch diameter in place of polyester. The fabric tended to slip on itself, since there was no cement at the coil intersections. The sample was 1/4-inch thick and weighed approximately 24 ounces/square yard. Further work should be done with this construction since, with the addition of a Beta glass fabric covering, high heat resistance could be obtained.

VI. PROTOTYPE FABRIC

The prototype spacer fabric supplied under this contract was made to the following specifications:

Spacer fabric

Weights	11-12 ounces/sq.yd.
Thickness (uncovered)	.245-.265 inches
Width (minimum)	42 inches
Construction length	17-18 yards
Compression strength (minimum)	8 psi
Coil spacing (center to center at assembly)	5/16-inch
Turns per inch (at assembly)	approximately 10

Monofilament

Polyester	Type VFR-1676-012
Diameter	.012-inch

Winding Mandrel

Diameter .25-inch

Cover Material

Nomex* fabric - flat jersey knit
Power net - 4.25 oz./sq.yd.
Neoprene sheet - .010 inch thick, 48 inches wide, tensile strength 1500 psi, elongation 300%

Cement for Cover Fabric

High viscosity, rapid-drying contact cement.

The following variations of spacer fabric were supplied:

100 yards - power net/spacer fabric laminate
25 yards - 2 plies of spacer fabric with sheet Neoprene spacer
50 yards - spacer fabric covered with stretch Nomex (both sides)
Three panels (15 inches x 20 inches) with integral heating wire.

VII. RECOMMENDATIONS

The work under this contract has demonstrated the feasibility of Monocoil construction as a spacer fabric, the emphasis being on a ventilating fabric to replace the nonstretchable spacer material used in experimental thermalibrium clothing under development at the U.S. Army Natick Laboratories.

The next step in the development of Monocoil is to explore the variety of applications for which this material seems uniquely suited. Typical functions which could be served are listed below:

1. Ventilation spacer
   a. as a fabric
   b. in air ducts

\- - - - -

* Trademark for nylon fiber.

2. Insulation spacer
    a. for light compression loads
    b. for high compression loads

3. Evaporative cooler (loaded with sponge)

4. Heater (with intermeshed resistance wire)

5. Vibration and/or sound damper.

This wide range of applications is possible because Monocoil can be readily adjusted to give the desired weight, thickness, load-carrying capability, stretch, and air flow characteristics. Most of these applications would be further benefited by making the respective constructions heat or flame-resistant.

Based on the work to date and previous experience with spacer fabrics, it is recommended that the further development of Monocoil include the following:

1. Ventilation Spacer - Develop a family of Monocoil ventilating constructions wherein due consideration is given to the problems involved in fabricating, handling, and applying the material.

Specifications concerned with stretch and load-carrying should be reviewed with the hope of improving other important characteristics. The present standard is more stretchable and resists a higher load than is probably necessary for most applications. Its use in air ducts should be demonstrated.

2. Insulation Spacer - Incorporate a variety of fillers into a range of Monocoil constructions and determine the heat transfer characteristics under compression loads typical of applications to be encountered.

By maintaining an air gap, Monocoil constructions are by themselves moderately good insulators. This quality can be improved substantially, however, by filling the air space with a foam or fibrous product to reduce internal eddy currents and the heat transfer that these currents produce. Goose down would be a preferred filler material here. Clothing and sleeping bags are typical applications for the use of this material.

Where high compression loads are encountered, as in the case of divers' clothing, it may be necessary to strengthen the Monocoil construction by incorporating crush- sistant fillers. Micro balloons and a variety of porous, granulated materials are possibilities to be considered. Hopefully, unicellular foam cast in a sturdy Monocoil matrix might prove to be sufficient. High-load-resistant Monocoil constructions will incur some weight penalty.

3. Evaporative Cooler - Fill Monocoil with an open cell elastomeric foam that would be capable of drawing water on demand from a reservoir via wicking, and test its efficiency as a cooler.

This construction would be made sufficiently flexible to be worn against the human body.

4. Heater - Construct Monocoil with intermeshed resistance wire to serve as a heater.

Applications could comprise a body-fitting therapeutic device, a heating blanket, or an anti-exposure suit fabric, for example.

5. Vibration and/or Sound Damper - Collect compression stress-strain data on a variety of Moncoil samples to determine their usefulness in vibration and/or sound damping clothing constructions.

6. Heat and/or Fire Resistant Fabric - Investigate the use of heat-resistant and/or nonflammable materials in Monocoil construction, and measure the effectiveness of Monocoil fabrics in protecting against flash fires.

Applicable heat-resistant materials would include (a) Nomex or polybenzimidazole multi-strand yarns heat-sintered into usable monofilaments, (b) wire, (c) hollow metal tubing, and (d) conventional monocoil materials coated with a fire-proofing material (metal plating, etc.). Facing materials would include Nomex, polybenzimidazole, glass and asbestos fabrics.

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13. ABSTRACT

An investigation was conducted to develop a 3-dimensional spacer fabric for use in the air distribution system of the experimental thermalibrium protective clothing system designed by the U. S. Army Natick Laboratories. A multidirectional-stretch spacer fabric known as "monocoil" made by interlocking coiled monofilaments in a square woven fabric-like configuration, was selected as the candidate system.

A variety of materials were studied. Based on analysis of available monofilaments, polyester was chosen as the material to be used in the construction of this 3-dimensional fabric.

Numerous monocoil designs were fabricated and tested for air flow, compression, weight, and stretch characteristics. A construction which met specifications was selected for quantity production. Two-hundred linear yards of experimental spacer fabric 42-48 inches wide were manufactured.

During development, it was found necessary to apply a protective or restraining cover to control stretch and enable handling of the spacer fabric. Cover materials included high-stretch power net, Jersey-knit Nomex fabric, and neoprene sheeting.

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Coils	2					
Spacers	4					
Fabrics	4					